Monitoring Moisture In Composting Systems

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"IF YOU SQUEEZE a handful of material and water drips or trickles out, it is the right moisture content for composting." This bit of hands-on wisdom comes from the proverbial squeeze-test for evaluating moisture in composting piles. It has been uttered by Master Gardeners and other composting educators for many years as a tool for determining, and teaching about, the balance of moisture in the composting process. Balance is the key word because, while moisture is necessary, too much can be detrimental. The squeeze-test mantra goes on to say that if you cannot squeeze any water out of the handful, the material is too dry and if water trickles out without squeezing, it is too wet.

Although the squeeze-test is useful, and often sufficient, for monitoring moisture in the composting process, it loses utility as the scale of composting grows larger and management becomes more scientific. Simply squeezing material is subjective and inexact, and it does not provide a quantitative measure of the moisture content. Therefore, composters have come to rely on other techniques to gauge moisture in the materials being composted and the compost produced. Such techniques range from the standard of drying and weighing samples to more recent electronic sensors that furnish an immediate reading or output signal.

Moisture Is Number One, But Heed The Sponge

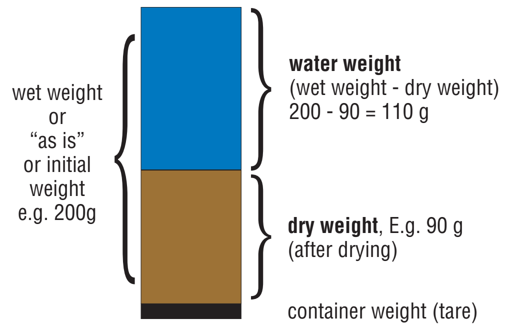
Assuming organic matter is already on hand, water is more important than any other composting requirement. Water is essential to biological decomposition. It allows organisms to live, acquire nutrients from their surroundings, and move about. It also provides a medium for chemical and biochemical reactions. Most composting organisms would be happy in a saturated environment except for the fact that they also need a continuous supply of oxygen. Too much moisture interferes with oxygen transfer and leads to anaerobic conditions. Decomposition continues anaerobically, but it is incomplete, creating odorous and phytotoxic compounds.

Another backyard composting adage states that compost should have the feel of a wrung-out sponge — damp but not dripping wet. Actually, a wrung-out sponge may be on the dry side for composting, but the analogy does provide a great image for understanding the reasons for balancing moisture. Like a compost pile (or windrow or material in a vessel), a sponge is a solid mass containing an enormous network of pores. The pore spaces hold moisture, air and other gases. The wrung-out sponge has a good deal of water in the pores, particularly the smaller pores, but it also contains open pores filled with air. Just as importantly, the open pores provide a passage for fresh oxygen-carrying air to enter and sponge gases to exit (pretend the sponge produces gases). The pores of a wet or saturated sponge, on the other hand, are filled with water so gases and air cannot easily pass. So goes the compost pile.

Quantifying Moisture Content

In quantitative terms, a wrung-out sponge represents a compost pile with a moisture content in the range of roughly 40 to 70 percent by weight (i.e. wet weight — see Figure 1). The range is estimated roughly because the limits depend on the feedstocks being composted (the type of sponge, to push the analogy). Coarse, porous materials like shredded brush aerate well enough at moisture contents as high as 70 percent while dense fine-particle materials, like grass clippings, may need to be kept below 60 percent moisture. The lower limit is determined not by aeration but by the mi-

Figure 1. Moisture mathematics



Wet Basis
percent moisture = 100% × water weight ÷ wet weight
= 100% × 110 ÷ 200 = 55%
percent solids = 100% × dry weight ÷ wet weight
or = 100% - %moisture = 100% - 55 = 45%

Dry Basis (rarely used in composting situations)
percent moisture (db) = 100% × water weight ÷ dry weight
= 100% × 110 ÷ 90 = 122%

croorganisms' need for moisture. The traditional benchmark for a noticeable slowing of biological activity is 40 percent moisture. However, most composters have found 50 percent moisture to be a better lower limit for rapid composting. Thus, generally, the ideal moisture content range for composting is 50 to 60 percent.

After composting yields compost, decomposition is no longer desired so handling considerations determine the desired moisture content of composts. It remains a balancing task that depends on how the compost will be handled and used. Wet compost, above 40 to 50 percent moisture, is difficult to screen, adds weight to transportation, and is less attractive to customers driving their hands into a freshly opened bag. Dry compost, below 30 percent, creates more dust. On the positive side, dry compost, in the range of 20 to 30 percent, can be applied with traditional equipment used for dry agricultural materials like lime. Compost with moisture in the range of 20 to 45 percent is susceptible to spontaneous combustion if it is stored in large undisturbed piles.

Determining Moisture Content — Gravimetric Methods

Besides the squeeze-test and look-and-feel evaluations, it is common to determine moisture content by weighing samples before and after the water is removed. In science-speak, such techniques are referred to as "gravimetric" methods. The basic concept is as follows: A sample of material is weighed to determine its wet weight (minus the weight of the container). Then the sample is dried to a point where all or nearly all of the water is evaporated and the sample is weighed again. This weight (minus the weight of the container) is the dry weight. The difference between the wet and dry weights is the weight of the water that the sample originally contained. Dividing the water weight by the wet weight gives the moisture content as a fraction (Figure 1).

The concept is simple enough, but it is not without technical pitfalls. Samples of compost and composting feedstocks contain volatile compounds (they evaporate). Any compounds that volatilize during drying confound the measurements. The difference between the wet weight and dry weight includes the weight of lost volatile compounds, in addition to the evaporated water. As the temperature increases more compounds volatilize. Furthermore, at high temperatures some organic matter may burn and form carbon dioxide and other volatile gases, confounding the measurements even more. Thus, if considerable organic matter is lost, the weight of water is overestimated and the dry weight is underestimated.

Determining moisture content for the purpose of monitoring the composting process does not require a great deal of accuracy. Thus, the loss of volatile organic dry matter in the drying step is rarely a significant factor. However, dry weight is used as the basis for determining concentrations of nutrients, heavy metals, and microorganisms. Inaccuracies in measuring moisture contents could overstate these qualities.

What differs among the various gravimetric methods is how samples are dried, how long they are dried, and, in some cases, what the sample size is. Drying methods include air drying, oven drying at various temperatures, and microwaves. Microwaves are quickest and most convenient but also the least accurate. Air drying is painfully slow but most accurate if the material is not actively decomposing. Oven drying is the middle ground and tends to be the standard.

Standard oven-drying procedures exist for analytical laboratories. The primary intent is to insure accuracy in determining dry weights, as the basis for calculating concentrations, rather than managing moisture during processing. The EPA standard method for determining moisture or solids content for biosolids calls for vented oven drying at 103 to 105°C (217 to 221°F) until the sample essentially stops losing weight. The method advocated within the U.S. Composting Council's Test Methods for the Examination of Composting and Compost suggests oven drying at 65 to 75°C (149 to 167°F) until no change in weight is observed. The temperature range of the EPA method is above the boiling point of water, so drying takes place relatively quickly — in a matter of hours. At the TMECC-recommended temperatures complete drying may require one to two days. The lower temperature of the TMECC approach is intended to improve the accuracy of dry weight determinations by minimizing the loss of volatile compounds.

Again, determining moisture content for the purpose of managing the composting process or the handling characteristics of compost does not merit great accuracy and precision. "About 50 percent moisture" is usually good enough. Therefore, drying samples in a microwave oven is also usually good enough, in addition to being fast and convenient. Drying occurs in minutes rather than hours. However, as in reheating last night's pizza for breakfast, the time depends on the power of the microwave and the sample size and moisture content. A set procedure can be worked out by trial and error. After a standard sample size is established, a sample is dried in the microwave oven for a short period and then weighed. This step is repeated until the sample weight shows little change, less than one percent of the original weight, for instance. Once an approximate total drying time is determined, the intermittent drying and weighing steps can be reduced or eliminated. As an example, starting with a 600 watt microwave and a sample of 100 grams (3.5 ounces), heat wet samples (50 to 80 percent) for six to eight minutes and dry samples (20 to 40 percent) for four to six minutes. Remove the sample, weigh it and place it back it the microwave oven, rotating its position by 90 degrees (unless the microwave has a rotating platform). Heat the sample again for two minutes, weigh it, and return it to the oven, rotating it another 90 degrees, in the same direction. Repeat the procedure at one-minute heating intervals until the weight change is less than one gram. The total heating time can be the basis for drying samples of similar moisture. (Note to readers: If the end of the fiscal year brings a must-spend budget surplus, there are computerized laboratory-scale microwave ovens available that track the weight of samples during drying and can calculate the moisture loss and moisture content automatically.)

A few simple steps can help decrease the inaccuracies associated with microwave drying. Use shallow sample containers that can be intermittently stirred or shaken as well as rotated. Beware of small flakes of metal in the samples. Metal causes sparks in the microwave oven that can char parts of the sample. In any case, discard samples that look or smell like they have been charred. Because microwave ovens heat unevenly, several short repeated heating steps are less likely to burn samples than a single uninterrupted heating step.

When a high degree of accuracy is necessary, there are good practices that apply to all gravimetric methods. Use a precise scale for weighing that can read 0.1 gram divisions (0.01 grams is better). The weight of sample containers should be accurately determined before filling. When using paper containers, dry the container first to drive off its moisture. Ideally, after heating and before weighing, samples should be stored in a desiccation chamber until they cool to ambient room temperature. Warm samples can reabsorb moisture from the air. If a desiccation chamber is not available, weigh samples as promptly as possible after removing them from the oven. Generally, working with larger samples creates less error than smaller ones. Finally, and most importantly, always get a good representative sample of the material and run multiple analyses.

Moisture Sensors — When You Just Can't Wait

When even a microwave oven is too slow and cumbersome, operators can turn to monitoring instruments with sensors that give a nearly immediate estimate of moisture levels. Sensors correlate moisture content with changes in some quickly-measurable property of the material such as electrical conductivity. They are common for measuring moisture levels in soil to determine when to irrigate. In some cases, sensors automatically activate irrigation equipment. However, determining moisture levels in composting media is more challenging than soil. First, the range of moisture levels in composting situations is much broader than in soils. Secondly, conditions within a composting pile or a pile of compost vary great from one location to the next. Thirdly, the moisture held by organic materials is difficult to detect because of the complex arrangement of pores. Even the pores of a sponge seem organized by comparison. Also, sensors make poor contact with compost media due to the course texture of compost and composting feedstocks. For all of these reasons, soil moisture sensors cannot readily be used in composting situations.

A few commercial moisture sensing instruments have been developed or adapted for composting applications. Because of the difficulties of accurately determining moisture in composting materials, they are promoted as devices that provide a quick-and-easy indication of moisture levels rather than an exacting measurement of moisture content. They tend to be portable, battery-powered instruments with a long stem for inserting into composting materials.

The Reo*Temp* moisture meter determines moisture levels via a sensor that measures electrical conductivity (opposite of resistance). A voltage is applied to the composting material between the electrodes of the sensor at the tip of the probe. Moisture is related to the electrical conductivity, which increases with increasing moisture levels. However, conductivity also changes with other factors like salt concentration and the nature of the substrate. Therefore, the meter is intended as a relative indicator of moisture level. It provides an instantaneous reading, giving a number between 0 (dry) and 10 (saturated). It is calibrated by inserting the probe into a saturated sample of material and then setting the meter to 10. With repeated use and consistent materials and conditions, operators acquire a sense of what moisture levels correspond to a reading of 2, 5, 6, 8 and so on.

Morgan Scientific offers a three-in-one monitoring instrument with the trade name Excalibur that measures temperature, oxygen, and moisture. Moisture is measured by drawing a sample of gas from pores of the pile or windrow. Moisture content is correlated with the relative humidity of the gas sample which, in turn, is determined by the sensor's electrical capacitance. After about a minute, the device yields an estimate of moisture content between 20 and 80 percent in increments of five percent. Measurements above 80 and below 20 percent are simply displayed as "wet" and "dry" respectively. As the five percent increment implies, the device provides an estimate of moisture content rather than a precise reading.

Other moisture sensing technologies have the potential to improve the accuracy of electronic sensors for organic materials. For instance, work is being conducted jointly by Pennsylvania State University and the University of Delaware on moisture sensors for mushroom growing beds, which are essentially compost. The technology being pursued is known as Time Domain Reflectometry (TDR). TDR uses an electronic pulse to measure the propagation of an electrical signal through the material. The time that it takes the signal to travel and return to the sensor depends on the amount of water present. In effect, this technique measures an electrical property known as the dielectric constant. Compared to other common substances, water has a uniquely high dielectric constant. Therefore, TDR is a promising technology for accurately detecting the amount of water held within a solid mass. E.S.I. Environmental Sensors Inc. is testing TDR moisture sensors for composting applications based on existing products used for soil moisture measurement. Conceivably, TDR technology could be accurate enough to automatically control water and aeration systems for composting.

The available moisture measuring instruments trade accuracy for ease of use and fast results. This is not to say that moisture sensors give erratic and incorrect results, but the precision and repeatability are not nearly as good as properly conducted gravimetric methods. Also, operators must become familiar with how the sensors behave with their particular materials under different conditions. On the other hand, moisture in composting materials can vary tremendously. An accurate and precise

Measuring Moisture By Feel

WILL Bakx of Sonoma Compost Company has a master's degree in soil science, but when it comes to measuring compost moisture content, he treats it more like the art of cooking than science. Here's his technique:

Take a sample of compost in your hand from roughly 18 to 24 inches into the pile. Make sure there are no sharp objects in the sample. Squeeze tightly. If water flows freely out of your hand, the moisture content is 65 percent or higher — too wet. If a few drops of water are visible between your fingers, you are right at 60 percent — the upper limit.

If you don't see any water, open up your hand and if a sheen is clearly visible, moisture content will be at 55 to 60 percent. If no sheen is visible and a ball remains in your hand, tap the ball gently. If the ball stays intact, moisture content is 50 to 55 percent. If a ball forms but breaks apart during tapping, moisture content will be 45 to 50 percent. When opening your hand and the compost does not remain in a ball, moisture is 40 to 45 percent or less. If, when discarding the material from your hand, a dry talcum-like feeling remains on your hand and no ball had formed, moisture content is likely below 40 percent, which slows down composting process.

Laboratory testing of compost samples has proven these moisture ratings to match descriptions. Of course, this nonscientific technique is specific to SCC's compost. Percentages may vary with different feedstocks. Bakx adds, however, that experience will allow any composter to fine-tune this method to their specific product.

moisture content reading from a single sample means little if the moisture content throughout a windrow is "all over the map." The moisture sensing devices provide the advantage of being able to measure moisture at many locations, many times faster than sampling, weighing and drying.

Summary

Because moisture is the most critical factor in composting, it must be monitored on some level. For many composters who are attuned to the art of composting, the squeeze-test is better than good enough. And why not? It is immediate, hands-on, inexpensive, and reflects the functions of moisture in the composting process. In fact, truly sensitive composters may not even need to squeeze. However, the squeeze-test is a subjective technique in an increasingly objective field. It always helps, and is often necessary, to have quantitative measures of moisture. Knowing the moisture content in quantitative terms gives operators an understanding of process conditions, marks progress in producing compost, and gives a definitive signal for adding water, turning on blowers, screening, bagging compost, or irrigating biofilters. Procedures that are accurate and precise should be used when reporting data based on dry weight to support marketing claims or to meet regulations (e.g., metals and pathogens). At a minimum, commercial-scale compost producers should be accustomed to determining moisture content by drying-and-weighing procedures. Electronic moisture sensors are available as additional management tools, although they cannot yet replace gravimetric techniques for quantifying moisture content. Eventually, moisture sensors may become a component of high-tech composting systems that automatically add water, engage aeration, and promote aeration and drying in response to process conditions. ■

Conserving Compost Moisture

A tremendous amount of water is evaporated during composting as a result of the process biochemistry, heat, and exposure to the sun and wind. In wet climates, occasional precipitation replenishes much of the lost water. However, in arid climates, and during dry periods in all climates, a great deal of water must be added to keep the process going. For example, Jim Doersam, manager of the Texas Organics Products composting facility in Austin, estimates that the facility uses an average of 18,000 gallons of water per day (as water and liquid feedstocks) to compost the 8,000 cubic yards of composting material contained in windrows on the site at any one time. While Texas is a particularly challenging climate, keeping up with moisture loss is difficult and expensive in any setting. Therefore, many compost operators have found ways to conserve moisture.

In passively aerated composting systems, water ultimately evaporates from the pile or windrow surface. Many attempts to conserve moisture reduce exposure or limit surface area for evaporation. Fewer turnings expose less moist materials to the drying winds and sun at the surface. Pile and windrow size can be increased to decrease evaporation because larger piles reduce the surface area per volume of material. This is similar to the strategy that composters in cold climates use to conserve heat during the winter. Thus, compared to small, frequently turned windrows, large static piles retain more moisture, and may even compost faster.

An alternative approach is to cover piles and windrows, blocking moisture movement without hindering aeration. The Texas Organics Products facility covers windrows with screening overs. Although the primary purpose is odor control, it also has the effect of reducing evaporation. Other facilities have used the same strategy using finished compost as the cover. Fabric covers, popular for keeping moisture from entering windrows and piles, also have the ability to slow moisture loss by shielding material from the wind and trapping vapors below the cover. This is evident in the condensation that takes place beneath the covers.

Moisture loss in forced aeration systems primarily results from air movement through the material. The best moisture conserving practice is to minimize the air flow rate without starving the process for oxygen or allowing temperatures to get too high. Covers and enclosures will also help to conserve moisture, assuming air can move freely.

Another moisture conserving strategy is to slow the process and reduce the heat of composting. Mixing energy-dense feedstocks with those that compost more slowly is one option. Dave Hogan, executive director of the Bluestem composting facility in Iowa, explains, "We notice less moisture loss with paper mill sludge in the composting recipe, in part because it is heavy in cellulose, which slows the process and lowers the heat production." The sludge also tends to form a crust that interferes with moisture loss (and aeration), although the crust is regularly broken up by turning (see article on page 26 about the Bluestem facility). Although intentionally slowing the process may seem counterproductive, it is not if lack of moisture is limiting the process anyway. In general, all moisture conserving practices occur at the expense of aeration or another process need.

Maintaining proper moisture content is more manageable if the feedstock mix starts with sufficient moisture and is not allowed to dry excessively. Adding water to already dry material can be a problem because dry materials are slow to adsorb it. Also, it simply takes a lot of water at one time to correct the situation.